J. Agric. Sci., Tokyo Univ. Agric., 59 (3), 169–176 (2014)
東京農大農学集報，59（3），169–176（2014）

論　文
Articles

Effects of Three Years of Continuous No P and No K Fertilization under Manure Application on Crop Yields and Soil Chemical Properties in Northern Japan, Hokkaido

By

Yasuo M. NAKAMARU*, Yusuke KOKIDO**, Marina SASADA*, Chinatsu TAKADA***
Javkhlantuya ALTANSUVD*, Shinya KASAJIMA*, Hirotake ITO*
and Hozumi YOSHIDA*

(Received January 10, 2014/Accepted July 25, 2014)

Summary：The Abashiri area in Hokkaido Prefecture is one of the most important agricultural areas in northern Japan. Due to long-term fertilization, most of the agricultural soil in this area has highly accumulated available P and K. In addition to this, typically about 450 kg P_2O_5 ha^{-1} and 780 kg K_2O ha^{-1} have been applied with 30 Mg ha^{-1} of animal manure every three years. In order to assess the possibility of decreased P and K fertilization using this accumulated P and K, we evaluated the effects of three years of continuous low or no P and K fertilization on crop productivity by a field experiment. From 2009 to 2011, sugar beet, potato, wheat and barley were cultivated using the major crop rotation system in this area. Four fertilization methods were used: i) Conventional NPK application, ii) Half P fertilization; iii) No P fertilization; and iv) No P and no K fertilization. Two Andosol fields (Urashibetsu A, B) and two Cambisol fields (Yasaka A, B) were used for this study. 30 Mg ha^{-1} of manure was applied to Urashibetsu A and Yasaka A field before the experiment. For Urashibetsu B and Yasaka B field, the same amount of manure was applied in 2007 and 2010, respectively. Especially in Urashibetsu B field, in 2010, oat was cultivated as green manure and plowed back into the field. The crop yield, soil available P and exchangeable K amounts, soil P fractions (Al bound P, Fe bound P, Ca bound P) were measured. As a result, almost no significant effects of P/K fertilization on crop yield were observed during three years. Due to manure application, soil available P and exchangeable K amount did not decrease because of the three years of no P and no K application. Manure application for Urashibetsu A and Yasaka A fields also increased Ca bound P fraction and decreased Fe bound P fraction. These results suggested that manure application increased soil P availability not only as an organic P source but also as a contributor to Fe bound P utilization. From these results, we considered that decreased or no P/K fertilization method should be started the next year after manure application in Abashiri area.

Key words：Accumulation, Agricultural soil, Decreased fertilization, Manure, Phosphorus, Potassium

1. Introduction

The Abashiri area in northeastern Hokkaido Prefecture is one of the most important agricultural areas in northern Japan. Most of the agricultural soil in this area has highly accumulated available phosphorus (P) and potassium (K) due to long-term fertilization. YOSHIDA *et al.* reported that no decrease of yield was observed for sugar beet when P and K were not applied in one year of cultivation in the Abashiri area[1] (Abashiri, Hokkaido Prefecture, 44.0° North, 144.2° East). On Japanese farms, reducing P fertilization is a recent trend. MISHIMA *et al.* reported that the average P fertilizer use in Japan decreased from 315 kg P_2O_5 ha^{-1} in 1985 to 227 kg P_2O_5 ha^{-1}

* Tokyo University of Agriculture, Faculty of Bioindustry, Laboratory of Integrated Crop Management Science
** HOKUREN Federation of Agricultural Cooperatives, Sapporo, Hokkaido, Japan
*** Tohoku University, Graduate school of Agricultural Science, Amamiyamachi 1-1, Sendai City, 981-8555, Japan

Table 1 Crop rotation system and fertilization ($kg\,ha^{-1}$) method of each test field in the experiment from 2009–2011.

	Manure [1] (Sep.2008)			2009			2010						2011		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O				N	P_2O_5	K_2O
Urashibetsu A	Applied in 2008			Sugar beet			Potato						Winter wheat		
Conventional	420	450	780	160	250	160	100	180	130				100	150	100
P 1/2	420	450	780	160	125	160	100	90	130				100	75	100
-P	420	450	780	160	0	160	100	0	130				100	0	100
-P -K	420	450	780	160	0	0	100	0	0	Green manure [2]			100	0	0
Urashibetsu B				Potato			Oat as green manure			N	P_2O_5	K_2O	Winter wheat		
Conventional				100	180	130	60	0	0	22	9	48	100	150	100
P 1/2				100	90	130	60	0	0	22	9	48	100	75	100
-P				100	0	130	60	0	0	22	9	48	100	0	100
-P -K				100	0	0	60	0	0	22	9	48	100	0	0
Yasaka A	Applied in 2008			Sugar beet			Potato						Barley		
Conventional	420	450	780	160	250	160	100	180	130				60	100	80
P 1/2	420	450	780	160	125	160	100	90	130				60	50	80
-P	420	450	780	160	0	160	100	0	130				60	0	80
-P -K	420	450	780	160	0	0	100	0	0	Manure (Sep.2010)			60	0	0
Yasaka B				Potato			Winter wheat			N	P_2O_5	K_2O	Sugar beet		
Conventional				100	180	130	100	150	100	420	450	780	160	250	160
P 1/2				100	90	130	100	75	100	420	450	780	160	125	160
-P				100	0	130	100	0	100	420	450	780	160	0	160
-P -K				100	0	0	100	0	0	420	450	780	160	0	0

[1] Manure (average N, P_2O_5, K_2O content =1.4, 1.5 and 2.6%) 30 $Mg\,ha^{-1}$ was applied to Urashibetsu A and Yasaka A before the experiment. For Urashibetsu B and Yasaka B field, same amount of manure was applied in 2007 and 2010, respectively.
[2] Green manure (N, P_2O_5, K_2O content =1.4, 0.6 and 3.1%[4)]) was applied at average yield of Urashivetsu B in 2010 (1.6 $Mg\,ha^{-1}$)

Table 2 Soil properties for four test fields at the beginning of the experiment (2009) and root number density.

	pH (H_2O)	Available P_2O_5 [1] (mg P_2O_5 kg^{-1})	Phosphate adsorption coefficient[1)]	Exchangeable K_2O [1] (mg K_2O kg^{-1})	Root number density [2] (roots cm^{-2})
Urashibetsu A (Light-colored Andosol)					Sugar beet
0-20 cm	6.5	193	1351	1175	0.29
20-40 cm	6.2	202	1329	1398	0.60
40-60 cm	6.2	100	1338	1243	0.45
60-80 cm	6.3	13	752	615	0.13
Urashibetsu B (Light-colored Andosol)					Potato
0-20 cm	5.5	297	1233	838	0.36
20-40 cm	5.9	337	1164	907	0.36
40-60 cm	6.4	29	784	908	0.34
60-80 cm	6.3	32	669	723	0.08
Yasaka A (Gray Upland soil (Cambisol))					Sugar beet
0-20 cm	6.9	538	1233	465	0.52
20-40 cm	6.7	485	1164	449	0.36
40-60 cm	6.5	5	784	145	0.18
60-80 cm	6.5	7	669	180	0.06
Yasaka B (Gray Upland soil (Cambisol))					Potato
0-20 cm	5.6	458	1092	679	1.18
20-40 cm	5.8	368	1111	691	0.47
40-60 cm	6.5	15	761	665	0.26
60-80 cm	6.6	8	531	308	0.07

[1] Results are for the -P-K fertilization method of each field in June 2009.
[2] Results are for the Conventional fertilization method of each field in August 2009.

in 2005, and P efficiency increased from 15.0% in 1985 to 20.1% in 2005[2)]. Though the Hokkaido Prefectural government has also recommended reducing P/K fertilization, many farmers have tended to continue conventional P/K fertilization because of fear of the decline of yield and limited data on the long-term effects of low P/K fertilization. In order to test the possibility for decreased P/K fertilization, we evaluated the effects of three years of continuous low or no P/K fertilization on crop productivity with a field experiment. In this study, under three years of continuous decreased P/K fertilization, the crop yield, P/K uptake of crops, soil available P/K amount, and changes of soil P fraction (Al bound P, Fe bound P, Ca bound P) were measured for fields of the two soil types.

2. Materials and Methods

In the Abashiri area, the root distribution of subsoil was identified as one of the most important factors influ-

Table 3 The crop yield ($Mg\,ha^{-1}$) [1] of each test field in the experiment from 2009–2011.

Fertilization method	2009		2010	2011	
Urashibetsu A	Sugar beet (root)	(Sugar production) [2]	Potato (tuber)	Winter wheat (grain)	
Conventional	71.1±2.3a[3]	(11.5±0.8a)	23.1±4.1a	9.4±1.9a	
P 1/2	69.0±8.2a	(11.1±1.6a)	23.1±1.2a	9.0±2.7a	
-P	74.8±4.3a	(12.1±0.7a)	23.6±3.9a	8.3±1.9a	
-P -K	77.0±10.7a	(12.0±1.5a)	28.2±3.5a	9.4±1.6a	
Urashibetsu B	Potato (tuber)		Oat as green manure	Winter wheat (grain)	
Conventional	63.0±9.8ab		1.44±0.31a	9.8±3.1a	
P 1/2	75.2±14.7a		1.87±0.55a	10.6±2.9a	
-P	67.2±5.1a		1.72±0.49a	8.2±2.9a	
-P -K	54.3±11.6b		1.20±0.25a	11.0±1.6a	
Yasaka A	Sugar beet (root)	(Sugar production) [2]	Potato (tuber)	Barley (grain)	
Conventional	68.0±3.4a	(11.3±0.7a)	58.7±14.6a	6.1±2.4a	
P 1/2	68.3±9.7a	(11.5±1.7a)	55.6±4.8a	5.6±2.8a	
-P	66.1±9.8a	(11.2±1.4a)	50.4±6.2a	6.3±1.8a	
-P -K	61.3±3.6a	(10.4±0.7a)	49.0±5.0a	5.5±1.0a	
Yasaka B	Potato (tuber)		Winter wheat (grain)	Sugar beet (root)	(Sugar production) [2]
Conventional	43.1±12.4a		5.7±0.7a	64.9±11.9a	(9.8±2.1a)
P 1/2	45.0±11.3a		5.6±0.6a	67.2±15.6a	(10.1±1.8a)
-P	44.4±10.9a		5.6±0.9a	62.7±26.6a	(9.3±3.6a)
-P -K	52.0±4.0a		5.5±0.7a	59.1±12.6a	(8.8±2.0a)

[1]Results are the average value and ± standard deviation of four replications. [2]For sugar beet, sugar production is also indicated.
[3]Values followed by different letters were found to be significantly different when comparing four fertilizations (ANOVA; $P<0.05$ by Bonferroni 's method).

encing crop productivity[3] and it was considered that the effective root depth affected the P and K availability to crops. Therefore, to test the effects of root distribution, four upland fields in the Abashiri area having two types of soil, Andosol and Cambisol, were used. The soil profile and root distribution of each field were investigated in 2009. According to the major crop rotation system used in the Abashiri area, sugar beet (*Beta vulgaris* ssp. *vulgaris*), potato (*Solanum tuberosum* L.), winter wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) were cultivated in this experiment. Four fertilization methods were used: i) Conventional NPK application, ii) Half P fertilization (P 1/2); iii) No P fertilization (-P); and iv) No P and no K (-P -K) fertilization. The experiment was started in May 2009, and each fertilization method was continued to November 2011. Especially in Urashibetsu B field, in 2010, oat (*Avena sativa* L.) was cultivated as green manure and plowed back into the field and so not harvested. The fertilization method and crop rotation system are summarized in Table 1. These four treatments were applied as four replicates in a randomized block design, resulting in a total of 16 experimental plots each in Urashibetsu A, B, Yasaka A and B field. Nitrogen (N) was added as Chilean saltpeter for sugar beet, and as ammonium sulfate for other crops. P and K were added as superphosphate and potassium chloride, respectively. According to the conventional fertilization method of this area, cow manure (average N, P_2O_5, K_2O content = 1.4, 1.5 and 2.6%) was applied as $30\,Mg\,ha^{-1}$ every three years after the wheat harvest.

After the cultivation, the crop yield and P and K uptake to plant were measured. Soil was sampled during cultivation. Soil samples taken from a depth of 0 to 20 cm were collected from each of the 16 plots in each of the field sites; soil was sampled monthly in the plant growing season (May to October) from 2009 to 2011.

Soil available P, Al bound P (Al-P), Fe bound P (Fe-P), Ca bound P (Ca-P), and exchangeable K were also measured. The soil available P was measured by the Truog method using pH 4 $(NH_4)_2SO_4 - H_2SO_4$ solution as an extractant[5,6]. The Truog method was used because it has been shown to be a suitable method for estimating plant available P of Japanese Andosols[7]. The Al-P, Fe-P and Ca-P were measured by the sequential extraction method using $1\,mol\,L^{-1}$ NH_4F for Al-P $0.1\,mol\,L^{-1}$ NaOH for Fe-P, and $0.5\,mol\,L^{-1}$ H_2SO_4 for Ca-P[8]. The exchangeable K amount was determined by the semi-micro Schollenberger method[9].

3. Results and Discussion

1) Soil properties of tested fields

According to the soil profile survey of each field in 2009, it was confirmed that the Andosol fields (Urashibetsu A, B) had a deep root zone (up to 1m depth), while in the Cambisol fields (Yasaka A, B), the root zone was limited by a clayey B horizon at 40 cm depth. The soil chemical properties and root distribution patterns (root number density) of the four test fields are shown in Table 2. Yasaka A and B were Cambisol fields and their root density was low in the subsoil. Soils in tested fields were found to be acidic and both exhibited high phosphate adsorption coefficients (1164–1351 mg P_2O_5 adsorbed to 100 g of soil) in the 0–40 cm depth.

2) Effects of decreased P/K fertilization on crop yield

The crop yields of each field in the experiment from 2009–2011 are shown in Table 3. For the three years, except for Urashibetsu B field in 2009, there was no significant statistical difference among the yields with four fertilizations for all the fields (The results are presented as the average of four replicates. The statistical software program used for ANOVA test by Bonferroni 's method was "Uchu-Yuki's UFO test version 1.0."). These results showed the possibility of decreased P/K fertilization in Abashiri area, however, for the recommendation of decreased fertilization to famers, the risk of the fertilization should be considered carefully. We thought that the soil property of Cambisol field could be one of the risk factors. In the Cambisol field (Yasaka A), average potato yield was lower at the end of the second year for -P and P 1/2 methods. In the third year, no decrease of yield for the –P –K method was observed in the Andosol fields (Urashibetsu A and B), but in the Cambisol fields (Yasaka A and B), the barley and sugar beet yields of the –P –K method were relatively lower than that of the –P method. This result should be due to the lower exchangeable K amount in Yasaka A and B fields than in Urashibetsu A and B fields (Table 2). However, even though Yasaka A and B fields had more available P (400–700 mg P_2O_5 kg^{-1}) than Urashibetsu A and B fields (200–500 mg P_2O_5 kg^{-1}), the decrease of crop yield with decreased P/K fertilization was more likely to occur in the Yasaka A and B fields. For the P uptake by plants, root length is the dominant factor controlling P uptake because of the low P solubility in soil solution[10]. Possibly the limited root distribution in Yasaka A and B fields could be the major factor to explain the lower yield, due to the lower efficiency of P uptake.

3) Effects of decreased P/K fertilization on soil available P and exchangeable K content

The changes of soil available P and exchangeable K during the experiment are shown in Table 4. For soil available P, though the Conventional fertilization method tended to result in higher values, for Urashibetsu A and Yasaka A fields, the values increased in 2010, and then decreased in 2011, for all four fertilization methods. For Urashibetsu B and Yasaka B fields, values increased in 2011. These trends could be attributed to the application of animal manure and green manure. In 2008, animal manure was added to the soil of Urashibetsu A and Yasaka A fields, and in 2010, green manure and animal manure was applied for Urashibetsu B and Yasaka B, respectively (Table 1). The increase of available P would be explained by the mineralization of organic P in the manure.

For the soil exchangeable K content, though irregular changes were observed for all fields from 2009 to 2011, the –P –K fertilization method gave relatively lower values than the other methods. During the cultivation from 2009–2011, both available P and exchangeable K values were within or beyond the recommended values set by the Hokkaido Prefectural government (100–300 mg P_2O_5 kg^{-1} and 150–300 mg K_2O kg^{-1}, respectively). In the Abashiri area, another field cultivation experiment of potato without P/K fertilization from 2007 to 2009 also showed that no P fertilization could not decrease soil available P immediately[11]. In that experiment, the annual decreases of available P and exchangeable K were -6 mg K_2O kg^{-1} and 88 mg K_2O kg^{-1}, respectively.

Table 4 Soil available P[1] and exchangeable K[1] (0–20 cm soil) of each plot at the beginning and the end of the cultivation in 2009–2011.

	Available P (mg P_2O_5 kg^{-1})						Exchabgeable K (mg K_2O kg^{-1})					
	2009		2010		2011		2009		2010		2011	
Urashibetsu A	29-May	15-Oct	25-May	11-Aug	16-May	21-Jul	29-May	15-Oct	25-May	11-Aug	16-May	21-Jul
Conventional	237	180	426	345	296	228	1350	973	1010	1270	880	1160
P 1/2	238	168	366	470	277	284	1216	1228	1190	1090	1120	1431
-P	245	193	228	359	209	263	1322	1053	1060	1040	1340	1341
-P -K	193	173	224	297	191	196	1175	1228	890	940	1130	1325
Urashibetsu B	29-May	15-Oct	21-May	11-Sep	16-May	21-Jul	29-May	15-Oct			16-May	21-Jul
Conventional	596	325	109	147	237	273	1300	811			910	759
P 1/2	375	233	95	130	238	237	1247	784			970	784
-P	303	200	138	133	237	215	1250	910			1020	811
-P -K	297	203	164	135	244	250	838	701			940	974
Yasaka A	2-Jun	16-Oct	25-May	30-Sep	2-Jun	28-Jul	29-May	15-Oct	25-May	11-Aug	2-Jun	28-Jul
Conventional	708	529	754	789	478	471	705	462	910	380	572	346
P 1/2	583	496	674	671	525	421	693	500	600	260	377	391
-P	479	373	589	556	444	385	833	457	740	380	387	343
-P -K	538	406	604	705	449	408	465	333	570	170	295	246
Yasaka B	2-Jun	16-Oct	22-May	20-Jul	9-Jun	13-Oct	29-May	15-Oct	22-May	20-Jul	9-Jun	13-Oct
Conventional	623	400	476	678	476	619	594	612	610	566	680	677
P 1/2	521	380	461	468	555	754	627	556	590	573	770	689
-P	447	371	444	455	511	453	610	596	630	571	630	611
-P -K	458	344	407	456	420	405	679	520	620	575	570	435

[1]Results are the average value of four replications.

Table 5 Soil phosphorus fractionation[1] (0–20 cm soil) of each plot at the beginning and the end of the cultivation in 2009–2011.

	Al- P (mg P_2O_5 kg^{-1})						Fe- P (mg P_2O_5 kg^{-1})						Ca- P (mg P_2O_5 kg^{-1})					
	2009		2010		2011		2009		2010		2011		2009		2010		2011	
Urashibetsu A	29-May	15-Oct	25-May	11-Aug	16-May	21-Jul	29-May	15-Oct	25-May	11-Aug	16-May	21-Jul	29-May	15-Oct	25-May	11-Aug	16-May	21-Jul
Conventional	1480	1571	1807	1914	1784	1563	732	713	435	513	589	512	223	238	489	529	421	491
P 1/2	1503	1443	1872	2335	2211	1406	689	683	467	533	481	402	234	227	526	682	511	554
-P	1629	1485	1495	1992	1935	1780	762	730	482	476	522	490	252	207	392	523	540	536
-P -K	1349	1312	1389	1731	1584	1511	650	640	435	497	504	512	200	196	327	420	500	328
Urashibetsu B	29-May	15-Oct	21-May	11-Sep	16-May	21-Jul	29-May	15-Oct	21-May	11-Sep	16-May	21-Jul	29-May	15-Oct	21-May	11-Sep	16-May	21-Jul
Conventional	2121	1900	1990	2010	1829	1829	674	732	601	526	365	375	403	318	255	263	435	414
P 1/2	1967	1832	1990	2240	1822	1813	709	750	607	528	373	483	260	278	249	257	411	385
-P	1768	1737	2060	2180	1808	1441	687	734	578	533	370	483	241	238	267	265	362	365
-P -K	1700	1636	1730	2270	1703	1311	640	668	551	532	379	362	246	261	265	263	383	348
Yasaka A	2-Jun	16-Oct	25-May	30-Sep	2-Jun	28-Jul	2-Jun	16-Oct	25-May	30-Sep	2-Jun	28-Jul	2-Jun	16-Oct	25-May	30-Sep	2-Jun	28-Jul
Conventional	1696	1551	1553	1735	1290	1520	658	633	431	405	388	471	315	285	517	561	447	490
P 1/2	1380	1437	1327	1477	1140	1340	630	676	405	308	366	421	263	250	447	508	425	419
-P	1032	1296	1384	1383	1080	1380	613	630	355	303	305	385	269	192	494	528	414	407
-P -K	1013	1371	1384	1627	1180	1290	599	624	364	338	378	408	311	231	466	589	416	409
Yasaka B	2-Jun	16-Oct	22-May	20-Jul	9-Jun	13-Oct	2-Jun	16-Oct	22-May	20-Jul	9-Jun	13-Oct	2-Jun	16-Oct	22-May	20-Jul	9-Jun	13-Oct
Conventional	1229	1241	1241	1255	1402	1298	658	689	477	506	478	719	235	279	395	404	450	399
P 1/2	1294	1112	1211	1180	1340	1451	630	650	486	484	463	510	289	256	389	357	400	432
-P	1145	1080	1189	1090	1185	1041	613	600	477	438	431	457	270	277	366	338	400	331
-P -K	1148	1073	1094	1054	1157	972	599	636	492	453	566	473	283	261	354	345	359	302

[1]Values are the average of four replications.

Table 6 The phosphorus and potassium uptakes and balances[1] by crops (kg ha^{-1}) of each test field.

	P_2O_5 uptake			P_2O_5 balance			K_2O uptake			K_2O balance		
Field and plot	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011
Urashibetsu A	Sugar beet	Potato	Winter wheat				Sugar beet	Potato	Winter wheat			
Conventional	62	65	212	638	753	691	134	277	265	806	658	494
P 1/2	55	64	169	520	546	452	154	286	323	786	631	408
-P	60	66	220	390	324	104	181	279	445	759	611	266
-P -K	57	67	164	393	326	162	154	283	224	626	343	119
Urashibetsu B	Potato	Green manure	Winter wheat				Potato	Green manure	Winter wheat			
Conventional	105		158	75	75	67	329		256	-199	-199	-355
P 1/2	121		192	-31	-31	-148	382		256	-252	-252	-407
-P	108		164	-108	-108	-272	361		185	-231	-231	-316
-P -K	93		137	-93	-93	-230	309		210	-309	-309	-520
Yasaka A	Sugar beet	Potato	Barley				Sugar beet	Potato	Barley			
Conventional	63	104	321	637	713	492	107	288	178	833	675	577
P 1/2	70	90	298	505	505	257	119	279	157	821	672	596
-P	64	76	367	386	310	-57	111	250	173	829	709	616
-P -K	56	70	385	394	324	-61	79	256	173	701	445	272
Yasaka B	Potato	Winter wheat	Sugar beet				Potato	Winter wheat	Sugar beet			
Conventional	62	231	117	118	37	620	156	239	141	-26	-165	634
P 1/2	80	214	120	10	-129	326	211	247	123	-81	-228	589
-P	81	190	114	-81	-271	65	212	231	136	-82	-213	591
-P -K	98	237	106	-98	-335	9	274	281	110	-274	-555	115

[1]Phosphorus and potassium balances were calculated as the difference between the accumulation of nutrient amount fertilized (see Table 1) and the uptake for each year.

4) Changes of phosphorus fraction of soil during 2009–2011

Changes of soil Al-P, Fe-P, Ca-P are shown in Table 5. While soil total inorganic P and Al-P amounts did not change clearly for any of the fields, Ca bound P was increased during three years, and the increase was especially obvious for Urashibetsu A and Yasaka A fields. The amount the Ca-P fraction increased in Urashibetsu A and Yasaka A fields was around 300 mg P_2O_5 kg^{-1}, and was almost the same level as the increase of soil available P. These increases of Ca-P and available P could be explained by the manure application in the Urashibetsu A and Yasaka A fields. On the other hand, the amount of Fe-P decreased, and the decrease was 253 mg P_2O_5 kg^{-1} and 236 mg P_2O_5 kg^{-1} for Urashibetsu A, and Yasaka A fields, 93 mg P_2O_5 kg^{-1} and 142 mg P_2O_5 kg^{-1} for Urashibetsu B, and Yasaka B fields (average of four plots), respectively. This would be explained by the manure application in 2008 for Urashibetsu A, and Yasaka A fields. Many studies have reported a similar effect of organic fertilizer on soil P fraction. HIRATA *et al.* reported that application of manure decreased Fe-P fraction in a 9-year continuous experiment on a Japanese upland Andosol field[12]. LI *et al.* also reported that the amount of Fe-P decreased with the application of organic fertilizer in a pot experiment; they explained that the manure application increased organic P mineralization due to microbial activity[13], which was also reported by TAKEDA *et al.*[14], and Li *et al.* also mentioned that the reduced P adsorption contributed to increased P availability[13]. The present field experiment results also suggested that organic fertilizer could enhance soil P availability not only as a P source but also as a contributor to increase P availability.

5) The P and K uptake of crops and the P and K balance of the tested fields

The P and K uptake of crops and the balance of P and K in the experiment are shown in Table 6. The P and K balance was calculated by the P and K uptake and the fertilized P and K amount shown in Table 1. The uptake values were calculated for sugar beet root, potato tuber, wheat grain and shoot, and barley grain and shoot. The P balance data did not accounted the green manure application in Urashibetsu B field because there was no input and no output of P and K by green manure. For P, the P uptake values did not decrease clearly with the decreased P fertilization except for the potato P uptake for Yasaka A in 2010. However, the P balance was a negative value for the Urashibetsu B and Yasaka B fields in 2010. The value of Yasaka B field turned to be positive in 2011 but the value of Urashibetsu B field remained negative in 2011. These results were due to the manure application in 2008 and 2010 (Table 1) and corresponded to the results of the changes in soil available P. For the K uptake by crops of Urashibetsu A and Yasaka B in 2011, the values for the –P–K fertilization method tended to be lower than the other fertilization method. K balance also reflected the manure application; the Urashibetsu B and Yasaka B fields had negative values from 2010.

These P/K balance and soil available P and exchangeable K data showed that the conventional manure application (10 Mg ha^{-1} y^{-1}) could maintain soil P and K amount without fertilization in Abashiri area. With the results of crop yield data in Urashibetu area, winter wheat yield of no P and/or no K plots in Urashibetsu A and Urashibetsu B were the same level though the P and K balance was negative in Urashibetsu B field. This suggested that the soil accumulated P was sufficient to maintain wheat productivity even under the three years of no P and/or no K application.

4. Conclusion

The crop yield in four fields did not change significantly when decreased P/K fertilization was used during a 3-year experiment regardless of the different soil type.

For the soil available P/K, the accumulated P/K in soil did not decrease significantly for the three years of No P and no K fertilization, and was increased by the manure application. Therefore the decreased P and no K fertilization method should be started the next year after manure application.

Acknowledgements

The authors thank the following persons for cooperating in the study : Tomoharu IKEDA, Tomohiro YAMAI, Suguru SHIBATA, Tetsu SIBASHAKI, Kazuto YANAI, Shingo SUZUKI, Susumu TATEE, Yasunari NIIKUNI, Shotaro OHYAMA, Tomonori SUSA, Yusuke SUGAYA, Toru KANAI, Nobuhiro SATAKE, Yuji WATANABE, and Yukio SHIRAHASE.

References

1) YOSHIDA H, ITOH H, KOMATSU T (2005) Effect of reduced phosphate and potassium fertilizer on sugar beet production in the Abashiri area. Jpn. *J. Crop Sci.* **74** : 450–455.
2) MISHIMA S, EBDO A., KOHYAMA K (2010) Recent trends in phosphate balance nationally and by region in Japan. *Nutr. Cycl. Agroecosyst.* **86** : 69–77.
3) ITOH H, HAYASHI S, NAKAJIMA T, HAYASHI T, YOSHIDA H, YAMASZAKI K, KOMATSU T (2009) Effects of soil type, vertical root distribution and precipitation on grain yield of winter wheat. *Plant Prod. Sci.* **12** : 503–513.
4) Hokkaido research organization (2002) The application guideline of green manure. (In Japanese), Hokkaido Research Organization, Agriculture Research Department, Kitami Agricultural Experiment Station, Kitami City.
5) TRUOG E (1930) The determination of the readily available phosphorus of soils. *J. Am. Soc. Agron.*, **22** : 874–882.

6) Blakemore LC, Searle PL, Daly BK (1981) Methods for Chemical Analysis of Soils. New Zealand Soil Bureau Scientific Report 10A. DSIR, New Zealand.

7) Kato N, Zapata F, Fardeau J C (1995) The ability of chemical extraction methods to estimate plant available soil P and a better understanding of P availability of fertilized Andosols by using isotopic methods. *Soil Sci. Plant Nutr.* **41** : 781–789.

8) Chang SC, Jackson ML (1957) Fractionation of soil phosphorus. *Soil Sci.* **84** : 133–144.

9) Schollenberger, CJ, Simon RH (1945) Determination of exchangeable capacity and exchangeable bases in soils. *Soil Sci.* **59** : 13–24.

10) Barber SA (1984) Soil Nutrient Bioavailability: A Mechanistic Approach. John Wiley, New York.

11) Kikuchi K, Tanaka H, Ikeda T, Nakamaru Y, Ito H, Kasajima S, Yoshida H (2012) Cultivation of Potato (Salanum tuberrosum) without phosphorus and potassium fertilization in Abashiri area. Jpn. *J. Crop Sci.* **81** : 404–413.

12) Hirata H, Watanabe K, Fukushima K, Aoki M, Imamura R, Takahashi M (1999) Effect of continuous application of farmyard manure and inorganic fertilizer for 9 years on changes in phosphorus compounds in plow layer of an upland Andosol. Soil Sci. *Plant Nutr.* **45** : 577–590.

13) Li X, Dong CX, Liu YR, Liu, YX, Shen, QR, Xu YC (2012) Interactive effects from combining inorganic and organic fertilizers on phosphorus availability. *Soil Research* **50** : 607–615.

14) Takeda M, Nakamoto T, Miyazawa K, Murayama T, Okada H (2009) Phosphorus availability and soil biological activity in an Andosol under compost application and winter cover cropping. *Applied Soil Ecology* **42** : 86–95.

北海道において堆肥の施用下で３年間リン，カリウムを無施肥とした場合の作物収量および土壌理化学性への影響

中丸康夫*・小木戸勇介**・笹田真里奈*・高田千夏***・Javkhlantuya ALTANSUVD*
笠島真也*・伊藤博武*・吉田穂積*

（平成 26 年 1 月 10 日受付/平成 26 年 7 月 25 日受理）

要約：北海道網走地域は北日本の最も重要な農業地帯の１つである。長期にわたる施肥によって同地域のほとんどの農耕地土壌には過剰に蓄積した可給態リン，カリウムが認められる。さらに，この地域では 3 年間に 1 回，およそ 30 Mg ha^{-1} の堆肥の施用によって，リンとカリウムが約 450 kg P_2O_5 ha^{-1}，780 kg K_2O ha^{-1} 程度投入されている。この蓄積したリンおよびカリウムを利用し，リンとカリウムの減肥が可能であるかどうか評価するため，圃場試験を行った。テンサイ，バレイショ，コムギおよびオオムギを用いたこの地域内の典型的な輪作体系の中で栽培した。その際施肥条件として，i）慣行 NPK 施肥，ii）リン半量施肥；iii）無リン施肥；iv）無リン，無カリ施肥をそれぞれ設けた。試験圃場として，黒ボク土圃場 2 圃場（Urashibetsu A, B），灰色台地土圃場 2 圃場（Yasaka A, B）の 4 圃場を使用した。試験開始前（2008 年）に堆肥 30 Mg ha^{-1} を Urashibetsu A および Yasaka A 圃場に施用した。Urashibetsu B および Yasaka B 圃場については，2007 年と 2010 年に同様に堆肥 30 Mg ha^{-1} が施用されており，特に Urashibetsu B 圃場には，2010 年に緑肥としてエンバクが栽培され，鋤きこまれている。これら圃場において作物の収量，土壌中可給態リン酸，交換性カリウム含量及び形態別リン酸（Al 型 P，Fe 型 P，Ca 型 P）を測定した。結果として，3 年間の試験においてリンおよびカリウム無施肥による収量への影響はほとんど認められなかった。堆肥の施用により，３年間のリン，カリウム無施肥処理においても土壌の可給態リン酸，交換性カリウム含量の減少は認められなかった。堆肥の施用はまた，Urashibetsu A および Yasaka A 圃場において Ca 型 P の増加および Fe 型 P の減少をもたらした。以上の結果は堆肥の施用が有機体リンの供給源としてのみならず本来不可給態である Fe 型 P の可給化によって土壌の可給態リンを増加させたことを示唆した。これらの結果から，リンおよびカリウムの減肥あるいは無施肥は堆肥の施用後に行うことが望ましいと考えられた。

キーワード：集積，農耕地土壌，減肥，堆肥，リン，カリウム

* 東京農業大学生物産業学部作物生産管理学研究室
** ホクレン農業協同組合連合会
*** 東北大学大学院農学研究科